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(54) **TURBOCOMPOUND INTERNAL COMBUSTION ENGINE**
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4,884,407 A 12/1989 Hatanaka 60/624
5,119,633 A * 6/1992 Brooks et al. 60/624
5,142,868 A * 9/1992 Woon et al. 60/624
5,555,730 A 9/1996 Hope 60/606
5,884,482 A * 3/1999 Lange et al. 60/624
6,286,312 B1 * 9/2001 Bertilsson 60/624

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(52) **U.S. Cl.** **60/624; 60/614; 60/602**

(58) **Field of Search** **60/624, 614, 602**

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,452,043 A * 6/1984 Wallace 60/624

FOREIGN PATENT DOCUMENTS

EP 0420705 A1 4/1991

* cited by examiner

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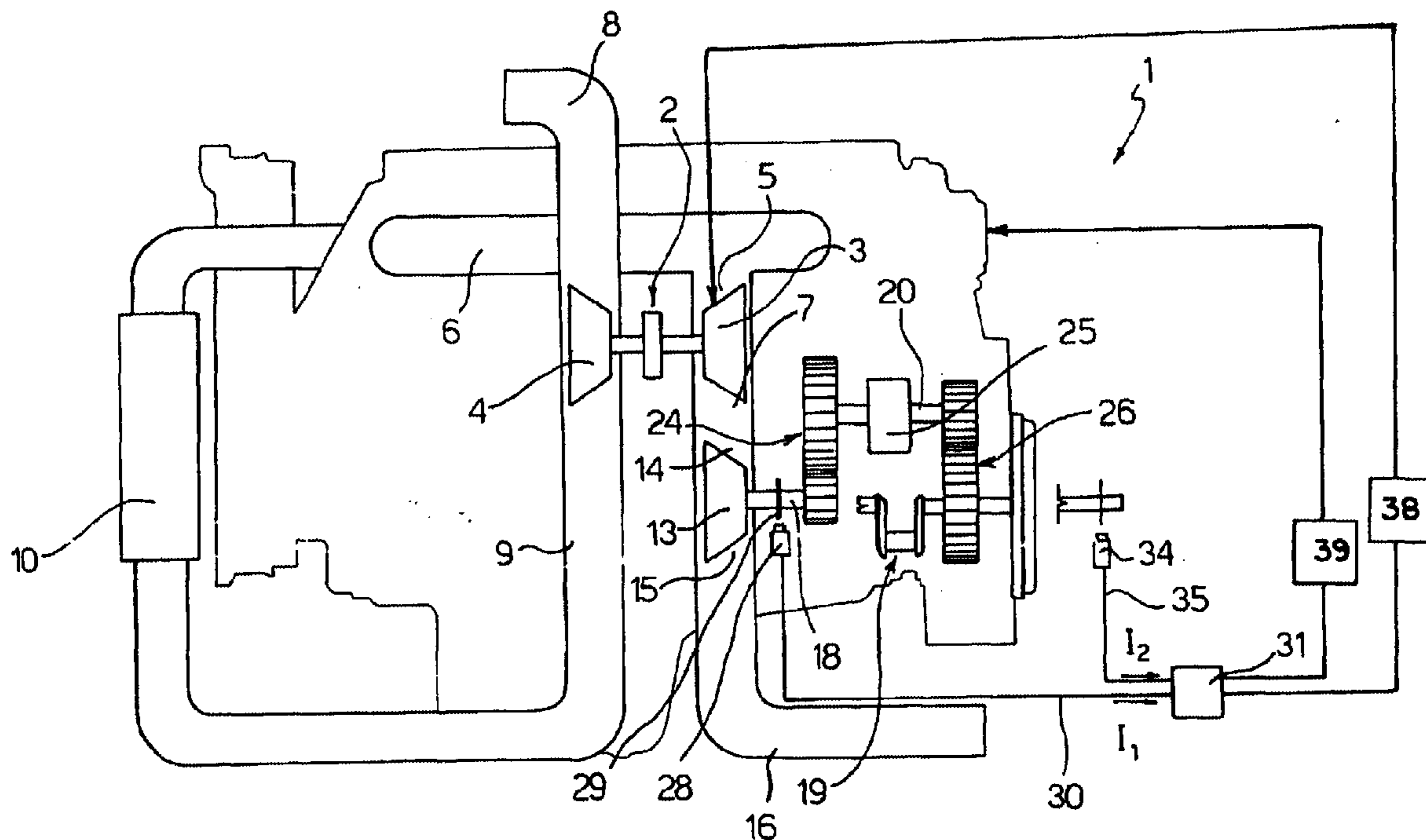
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(57) **ABSTRACT**

A turbocompound internal combustion engine having a turbocharger with a variable-geometry turbine; and an auxiliary turbine, which is located downstream from the turbine of the turbocharger, provides for recovering energy from the exhaust gas, and is connected mechanically to the drive shaft of the engine via a transmission; a control device compares the rotation speed of the auxiliary turbine, detected by means of a sensor, with a range of permissible speeds calculated on the basis of the speed of the drive shaft, and controls fuel supply to the engine and the geometry of the variable-geometry turbine to maintain the speed of the auxiliary turbine within predetermined limits in the event of a fault on the transmission.

9 Claims, 2 Drawing Sheets



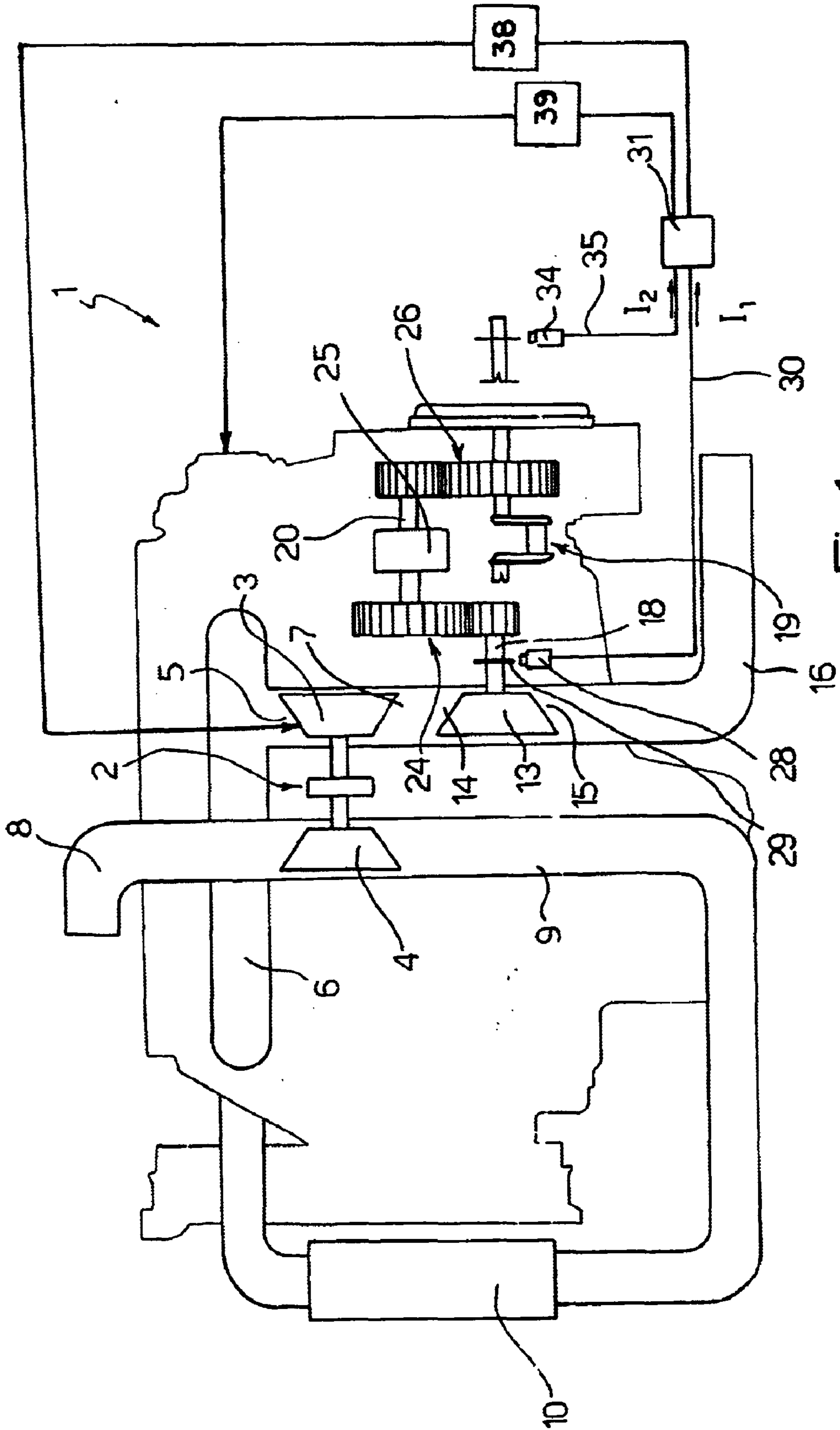


Fig.1

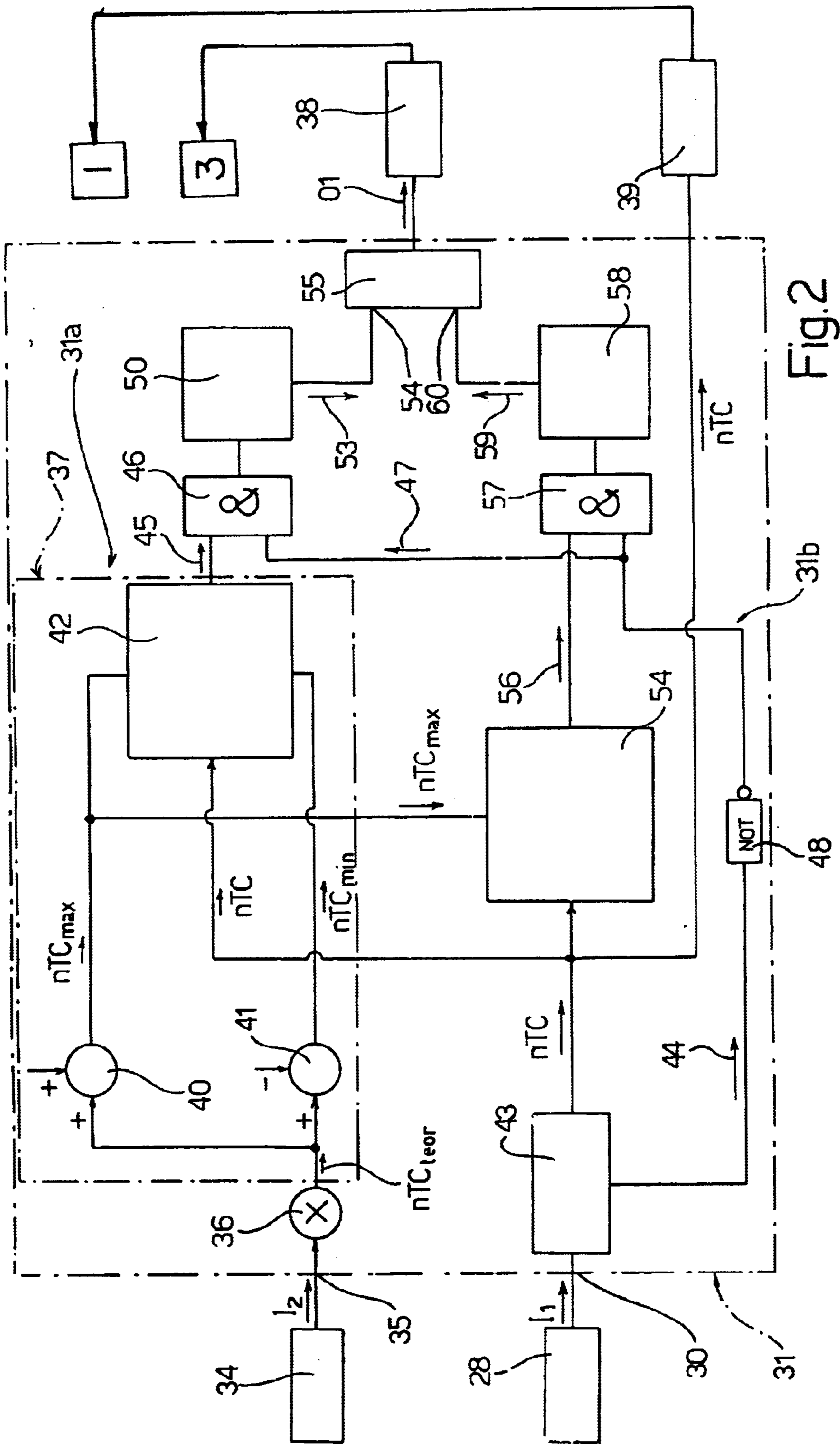


Fig. 2

TURBOCOMPOUND INTERNAL COMBUSTION ENGINE

The present invention relates to a so-called “turbo-
compound” internal combustion engine, in particular for an
industrial vehicle.

BACKGROUND OF THE INVENTION

“Turbocompound” internal combustion engines are
known, which comprise an auxiliary turbine downstream
from the turbocharger turbine and connected mechanically
to the drive shaft to recover and convert part of the residual
energy of the exhaust gas into mechanical power for the
drive shaft.

The auxiliary turbine and drive shaft are normally con-
nected mechanically (here intended in the broader sense of
the ability to transfer mechanical power, as opposed to a
“rigid connection”) by a transmission comprising a gear
reducer and a hydraulic joint permitting a certain amount of
“slippage”. In the event of a breakdown of the hydraulic
joint or relative hydraulic supply circuit, the auxiliary tur-
bine may become mechanically disconnected from the drive
shaft, and so unaffected by the braking torque produced by
rotation of the drive shaft, so that the speed of the turbine,
driven exclusively by the exhaust gas, may exceed the safety
limit, thus resulting in breakdown of the turbine.

By way of a solution to the problem, turbocompound
engines have been devised featuring a safety control device
for detecting the oil pressure of the hydraulic joint, and
which intervenes when the pressure falls below a predeter-
mined limit. This type of device, however, is only effective
and only intervenes in the case of hydraulic faults, whereas
faults in the torque transmission of the hydraulic joint have
been found to occur, for example, even when the system
circuitry is sound but the oil particularly dirty.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a
turbocompound internal combustion engine featuring an
auxiliary turbine speed control device designed to eliminate
the aforementioned drawbacks typically associated with
known devices.

According to the present invention, there is provided a
turbocompound internal combustion engine comprising a
drive shaft; a turbocharger comprising a turbine and a
compressor; an auxiliary turbine located along the path of
the exhaust gas, downstream from said turbine of said
turbocharger; and transmission means between said auxil-
iary turbine and said drive shaft; characterized by compris-
ing a first angular speed sensor for detecting the rotation
speed of said auxiliary turbine; and a control device for
controlling the rotation speed of said auxiliary turbine, and
which is connected to said first sensor and in turn comprises
calculating means for calculating a range of permissible
values of said rotation speed of said auxiliary turbine,
comparing means for comparing the rotation speed of said
auxiliary turbine measured by said first sensor with said
range of permissible values, and control means for control-
ling operating parameters of the engine in response to an
enabling signal generated by said comparing means, so as to
maintain said speed of said auxiliary turbine within said
range of permissible values.

The present invention also relates to a method of control-
ling a turbocompound internal combustion engine compris-
ing a drive shaft; a turbocharger comprising a turbine and a
compressor; an auxiliary turbine located along the path of

the exhaust gas, downstream from said turbine of said
turbocharger; and transmission means between said auxil-
iary turbine and said drive shaft; said method being char-
acterized by comprising the steps of measuring the rotation
speed of said auxiliary turbine by means of a sensor;
calculating a range of permissible values of said rotation
speed of said auxiliary turbine; comparing the rotation speed
of said auxiliary turbine measured by said sensor with said
range of permissible values; and controlling operating
parameters of the engine in response to the outcome of said
comparing step, so as to maintain said speed of said auxil-
iary turbine within said range of permissible values.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred, non-limiting embodiment of the present
invention will be described by way of example with refer-
ence to the accompanying drawings, in which:

FIG. 1 shows a diagram of a turbocompound engine in
accordance with the present invention;

FIG. 2 shows a block diagram of a control device of the
FIG. 1 engine.

DETAILED DESCRIPTION OF THE INVENTION

Number 1 in FIG. 1 indicates as a whole an internal
combustion engine for an industrial vehicle.

Engine 1 comprises a turbocharger 2 comprising a turbine
3 and a compressor 4 fitted to a common shaft. Turbine 3 has
an inlet 5 connected to an exhaust manifold 6 of engine 1,
and an outlet 7. Compressor 4 has an inlet connected to an
air intake circuit 8, and an outlet 9 connected to an intake
manifold (not shown) of the engine via an intercooler 10.

Engine 1 also comprises an auxiliary or power turbine 13
having an inlet 14 connected to outlet 7 of turbine 3, and an
outlet 15 connected to an exhaust system 16.

Auxiliary turbine 13 is fitted to a shaft 18, which is
connected mechanically to a drive shaft 19 of engine 1 by a
transmission indicated as a whole by 20.

More specifically, transmission 20 comprises a first gear
reducer 24; a hydraulic joint 25; and a second gear reducer
26 connected at the output to drive shaft 19.

According to the present invention, an angular speed
sensor 28—e.g. comprising a pulse generating wheel 29
associated with shaft 18 or any other member rotating at
fixed speed with respect to it—detects the rotation speed of
auxiliary turbine 13, is connected to a first input 30 of a
device 31 for controlling fuel supply and the geometry of
turbine 3, and supplies input 30 with a signal I1 related to the
speed of auxiliary turbine 13. A second sensor 34, of
conventional type (not shown) and associated, for example,
with the input shaft of the vehicle transmission to detect the
angular speed of the drive shaft (hereinafter referred to
simply as “engine speed”, is connected to and supplies a
second input 35 of device 31 with a signal I2.

FIG. 2 shows a block diagram of device 31.

Device 31 substantially comprises a first block 36 for
calculating the theoretical speed $n_{TC\text{teor}}$ of auxiliary tur-
bine 13 on the basis of signal I2. Block 36 is connected to
second input 35, substantially comprises a multiplier for
multiplying the engine speed value by a constant taking into
account the transmission ratio of transmission 20, and is
connected at the output to a block 37, which compares the
actual speed of the auxiliary turbine with a range of per-
missible values defined on the basis of the theoretical speed
calculated above. More specifically, block 37 comprises a

first adder **40**, which calculates a theoretical maximum speed nTC_{max} of auxiliary turbine **13** by adding a constant (e.g. 10,000 rpm) to nTC_{teor} ; and a second adder **41**, which calculates a theoretical minimum speed nTC_{min} of auxiliary turbine **13** by subtracting a constant (e.g. 20,000 rpm) from nTC_{teor} .

The two values nTC_{max} and nTC_{min} are supplied to a first threshold comparator **42** defining a range of permissible values of the speed nTC of auxiliary turbine **13**. Speed nTC is calculated in known manner, on the basis of signal **I1** from sensor **28**, in an interface block **43** connected to first input **30** of device **31**, and which also generates in known manner a diagnostic signal **44** indicating the operating state of sensor **28**, and having, for example, a 0 logic value when sensor **28** is operating correctly, and a 1 logic value in the event signal **I1** of sensor **28** is implausible, e.g. absent or inevaluable.

Threshold comparator **42** receives signal nTC from interface block **43**, and compares it with threshold values nTC_{max} and nTC_{min} . More specifically, threshold comparator **42** generates a digital signal **45** of value 1 if nTC is between nTC_{max} and nTC_{min} , and of value 0 if nTC is outside the range defined by nTC_{max} and nTC_{min} .

Signal **45** is supplied to one input of a first AND gate **46**, the other input of which is supplied with a signal **47** equal to diagnostic signal **44** inverted by a NOT gate **48**. The output of AND gate **46** is connected to a time filtering block **50**, which generates a signal **53** of the same logic value as the input signal when the input signal remains stable for a predetermined time interval. Signal **53** is supplied to a reset input **54** of a flip-flop **55**.

The nTC_{max} value calculated by first adding block **40** is used to set the switching threshold of a second threshold comparator **54**, which receives signal nTC generated by interface block **43**, and generates a signal **56** of logic value 1 if nTC is greater than nTC_{max} , thus indicating a malfunction of auxiliary turbine **13**, and of logic value 0 if nTC is less than nTC_{max} .

Output signal **56** from comparator **54** and output signal **47** from NOT gate **48** are supplied to the inputs of a second AND gate **57**.

The output of AND gate **57** is connected to a second time filtering block **58**, which generates a signal **59** of the same logic value as the input signal when the input signal remains stable for a predetermined time interval. Signal **59** is supplied to the set input **60** of flip-flop **55**.

Flip-flop **55** generates an output signal **O1**, which is supplied to a block **38** for controlling the geometry of turbine **3**, and to a block **39** for controlling fuel supply by the injectors. Block **39**, operation of which is described in detail later on, also receives signal nTC relative to the speed of auxiliary turbine **13**.

Operation of device **31**, partly obvious from the foregoing description, is as follows.

To begin with, sensor **28** is assumed to be operating correctly, so that signal **44** is of value 1 and has no effect on the outputs of AND gates **46**, **57**, which depend exclusively on the value of nTC .

If the speed nTC of turbine **13** falls within the range of permissible values, and sensor **28** is operating correctly, the output of first AND gate **46** is 1; and, if this value remains stable over time, the reset input of flip-flop **55** also equals 1.

If nTC falls within the range of permissible values, the condition $nTC < nTC_{max}$ is also definitely confirmed, so that the output of second threshold comparator **54** is 0, the output of second AND gate **57** is 0, and, if this value remains stable over time, the set input of flip-flop **55** is also 0.

The output signal **O1** of flip-flop **55** is zero, so there is no intervention on the part of blocks **38**, **39**.

The upper branch of the FIG. 2 block diagram—indicated as a whole by **31a**—therefore acts as a recognition circuit for determining correct operation.

If the speed nTC of turbine **13** does not fall within the range of permissible values, and sensor **28** is operating correctly, the output of first AND gate **46** is 0; and, if this value remains stable over time, the reset input of flip-flop **55** also equals 0.

If nTC is greater than nTC_{max} , the output of second threshold comparator **54** is 1, the output of second AND gate **57** is 1, and, if this value remains stable over time, the set input of flip-flop **55** is also 1.

In this case, signal **O1** equals 1 and a correction of the geometry of turbine **3** and fuel supply is enabled.

The lower branch **31b** of the block diagram therefore acts as a recognition circuit for determining a malfunction.

Conversely, if nTC is less than nTC_{min} , the output of second threshold comparator **54** is 0, the output of second AND gate **57** is 0, and, if this value remains stable over time, the set input of flip-flop **55** is also 0. Both the inputs of flip-flop **55** are 0, and the pre-existing situation is maintained.

The same applies in any case (i.e. regardless of the detected nTC value) in the event a fault is detected on sensor **28** (i.e. a 1 value of diagnostic signal **44**); in which case, signal **47** is 0, so that the outputs of both AND gates **46**, **57** are 0.

In the presence of a logic 1 value of signal **O1**, block **38** sets the geometry of turbine **3** to the full-open condition, thus reducing supercharging; and, at the same time, block **39** immediately reduces fuel supply by the injectors to a predetermined start value, and then modulates the full supply value to keep the speed of auxiliary turbine **13** constant and equal to an acceptable value, e.g. nTC_{max} .

The advantages of engine **1**, and particularly control device **31**, according to the present invention will be clear from the foregoing description.

In particular, by device **31** determining the rotation speed of auxiliary turbine **13**, any malfunction affecting the mechanical performance of the turbine is detected.

The control logic of device **31** only provides for correcting the operating parameters of the engine (geometry of turbine **3** and fuel supply) when the integrity of auxiliary turbine **13** is definitely at risk. That is, it does not intervene when the fault may possibly depend on a malfunction of sensor **28**, or when the fault does not threaten the integrity of turbine **13** ($nTC < nTC_{min}$).

Moreover, intervention is designed to still allow albeit emergency operation of the vehicle, by supply to the engine being controlled to prevent overacceleration of auxiliary turbine **13**.

Clearly, changes may be made to engine **1**, and in particular to device **31**, without, however, departing from the scope of the accompanying claims.

What is claimed is:

1. A turbocompound internal combustion engine comprising:
 - a drive shaft;
 - a turbocharger comprising:
 - a turbine and
 - a compressor;
 - an auxiliary turbine located along the path of the exhaust gas, downstream from said turbine of said turbocharger; and

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transmission means between said auxiliary turbine and said drive shaft

said engine further comprising:

- a first angular speed sensor for detecting the rotation speed of said auxiliary turbine; and
- a control device for controlling the rotation speed of said auxiliary turbine, and which is connected to said first angular speed sensor and in turn comprises:
 - calculating means for calculating a range of permissible values of said rotation speed of said auxiliary turbine,
 - comparing means for comparing the rotation speed of said auxiliary turbine measured by said first sensor with said range of permissible values, and
 - control means for controlling operating parameters of the engine in response to an enabling signal generated by said comparing means, so as to maintain said speed of said auxiliary turbine within said range of permissible values;
 - said calculating means for calculating said range of permissible values including a second angular speed sensor for detecting the rotation speed of the drive shaft: and processing means for calculating at least a maximum value of the speed of said auxiliary turbine on the basis of the speed of the drive shaft.

2. The engine as claimed in claim 1, characterized in that said turbine of said turbocharger is a variable-geometry type; said control means for controlling operating parameters of the engine comprising means for varying the geometry of said variable-geometry turbine.

3. The engine as claimed in claim 2, characterized in that said means for varying the geometry of the variable-geometry turbine comprise means for setting a full-open condition of said variable-geometry turbine.

4. The engine as claimed in claim 1, characterized in that said control means for controlling operating parameters of the engine comprise means for varying fuel supply, to maintain said speed of said auxiliary turbine within said maximum value.

5. The engine as claimed in claim 1, characterized in that said control device includes means for determining the plausibility of a signal received from said first sensor; and disabling means for disabling said control means for controlling operating parameters of the engine in response to detection of an implausibility condition of said signal.

6. A method of controlling a turbocompound internal combustion engine comprising:

- a drive shaft;
- a turbocharger comprising:
 - a turbine and
 - a compressor;
- an auxiliary turbine located along the path of the exhaust gas, downstream from said turbine of said turbocharger; and
- transmission means between said auxiliary turbine and said drive shaft;

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said method including the steps of:

- measuring the rotation speed of said auxiliary turbine by means of a first sensor;
- calculating a range of permissible values of said rotation speed of said auxiliary turbine;
- comparing the rotation speed of said auxiliary turbine measured by said first sensor with said range of permissible values; and
- controlling operating parameters of the engine in response to the outcome of said comparing step, so as to maintain said speed of said auxiliary turbine within said range of permissible values,

said operating parameters including the geometry of said turbine of said turbocharger and fuel supply of said engine.

7. The method as claimed in claim 6, characterized in that said step of controlling operating parameters of the engine comprises the operations of setting said turbine of said turbocharger to a full-open condition; and modulating fuel supply to maintain the rotation speed of the auxiliary turbine within a maximum limit.

8. The method as claimed in claim 6, characterized by comprising the steps of determining the plausibility of a signal received from said first sensor; and disabling said step of controlling said operating parameters of the engine in response to an implausibility condition of said signal.

9. A method of controlling a turbocompound internal combustion engine comprising:

- a drive shaft;
- a turbocharger comprising:
 - a turbine and
 - a compressor;
- an auxiliary turbine located along the path of the exhaust gas, downstream from said turbine of said turbocharger; and
- transmission means between said auxiliary turbine and said drive shaft; said method including the steps of:
 - measuring the rotation speed of said auxiliary turbine by means of a first sensor;
 - calculating a range of permissible values of said rotation speed of said auxiliary turbine;
 - measuring the rotation speed of the drive shaft of said engine by means of a second angular speed sensor;
 - calculating a range of permissible values of the speed of said auxiliary turbine on the basis of the speed of the drive shaft, said range being defined by at least a maximum value of the speed of said auxiliary turbine;
 - comparing the rotation speed of said auxiliary turbine measured by said first sensor with said range of permissible values; and
 - controlling operating parameters of the engine in response to the outcome of said comparing step, so as to maintain said speed of said auxiliary turbine within said range of permissible values.

* * * * *